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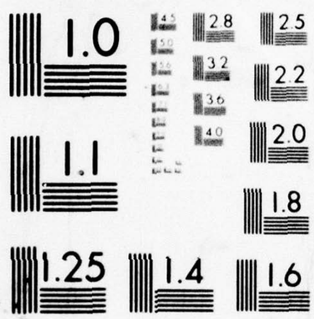

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THE EFFECT OF VIRTUAL IMAGE PROJECTION DISTANCE ON THE ACCOMMODATIVE RESPONSE OF THE EYE

Gloria Twine Chisum, Ph.D. and Phyllis E. Morway
Crew Systems Department
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

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Virtual image displays utilize either aircraft mounted or helmet mounted beam splitters, or combining screens. The effect on the accommodative response of the projection distance of the virtual image was measured by photographing the first and fourth Purkinje images of a source. The results indicate possible effect on the accommodation response. Further explanation of the problem is indicated.

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INTRODUCTION

Technological advances of recent years have made possible advanced display concepts and designs. One type of advanced display is that which presents to a user a virtual image reflected from a beam splitter in such a manner that the image reflected is seen at the same time as other environmental stimuli. The displays have evolved from the concepts involved in the original airborne gun and bomb sights. The virtual image displays which are currently in use or are in either a developmental or conceptual stage present various types of command and control information to aircrew users.[1]

The impetus for the development of the virtual image displays has come from several sources such as the lack of adequate sensor performance in the area of sensor-computer solution time and sensor settling time delays and the need to relieve aircrew personnel of the necessity for frequent shifts of gaze between the outside environment and the interior of the cockpit. The efficiency with which any display is used and the degree of accompanying user fatigue is significantly affected by the design of the display. Among the design considerations of concern with the virtual image displays are those which influgence the visual accommodation of the user[2]. The study reported here is designed to assess the effect of one of the display characteristics, image projection distance, on the accommodation of the user. Beam splitters simulating both the aircraft mounted virtual image displays and the crew personnel-mounted virtual image displays were utilized in conjunction with projectors in which the focus of the projected image could be varied. The accommodation of the observers was monitored by means of the first and fourth Purkinje images, those which are reflected from the front surface of the cornea and the rear surface of the lens.

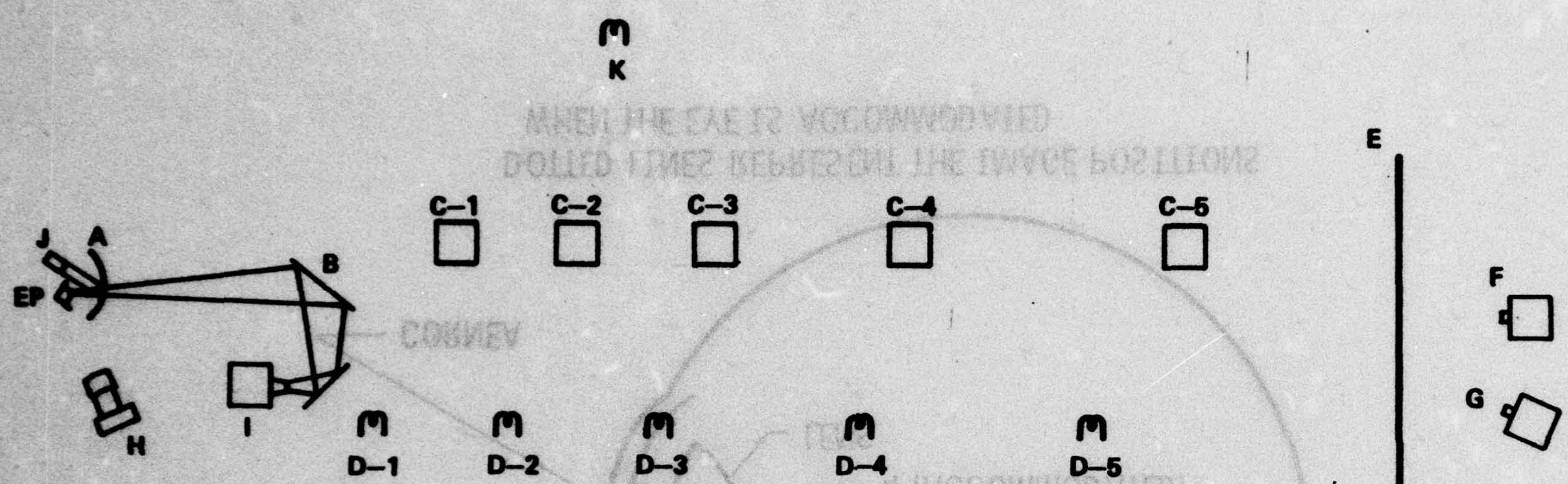
The information obtained from this study can be used to determine the tolerance limits for the precision required in the virtual image display design. The questions raised are particularly significant for the design of helmet mounted sights and displays since the rigidity of the entire optical system in those displays is less than optimum.

APPARATUS

The apparatus, shown diagramatically in Figure 1, consisted of three principal parts, the accommodation recorder, the accommodation calibrator, and the display device simulators.

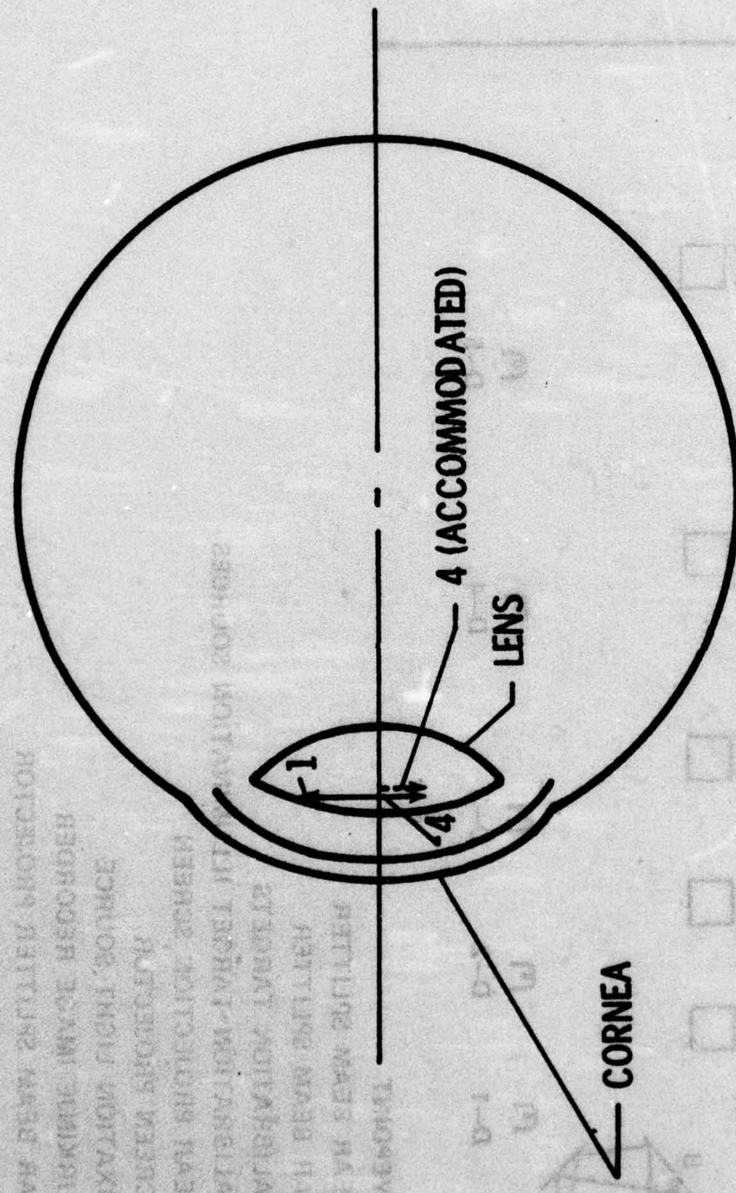
I. Accommodation Recorder

The accommodation recording portion of the apparatus consisted of a Canon 35mm camera, H, with a Vivitar 75 to 260mm Telezoom lens and two lens extenders, 20mm and 36mm, mounted at an angle of 27 degrees to the line of sight so that the eye of the observer located at the eyepoint (EP), filled approximately three-fifths of the 35mm film format. A xenon photographic flash lamp mounted at J, 2.19 meters from EP at an angle of 19 degrees to the line of sight, served as the source for the Purkinje images which were visible in the photographs of the eye of the observer, as well as a source of general illumination of the eye. The accommodative state of the eye was determined by measuring the distance between the first and fourth Purkinje images shown schematically in Figure 2 and as recorded in Figure 3.



EP = EYEPOINT
A = NEAR BEAM SPLITTER
B = FAR BEAM SPLITTER
C-1 – C-5 = CALIBRATION TARGETS
D-1 – D-5 = CALIBRATION TARGET ILLUMINATION SOURCES
E = REAR PROJECTION SCREEN
F = SCREEN PROJECTOR
G = FIXATION LIGHT SOURCE
H = PURKINJE IMAGE RECORDER
I = FAR BEAM SPLITTER PROJECTOR
J = NEAR BEAM SPLITTER PROJECTOR
K = PURKINJE IMAGE SOURCE

FIGURE 1. Diagram of Apparatus



DOTTED LINES REPRESENT THE IMAGE POSITIONS WHEN THE EYE IS ACCOMMODATED

FIGURE 2. Diagram of Purkinje Images

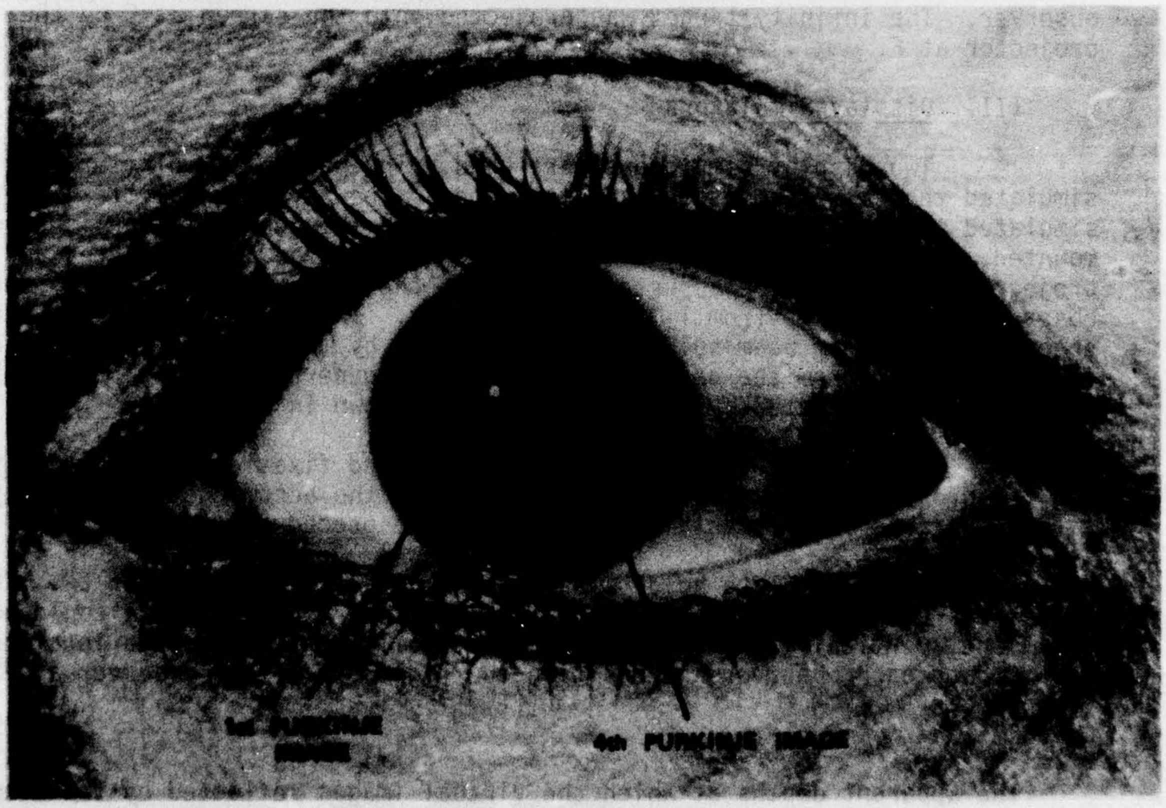


FIGURE 3. Photograph of Purkinje Images

II. Accommodation Calibrator

The accommodation calibrator consisted of the five targets C_1 through C_5 with their respective illuminators, D_1 through D_5 and the rear projection screen E. The targets, located at 1.25, 2.0, 2.5, 5.0, and 10.0 meters from EP were horizontal black and white line gratings adjusted in width so that the lines of all gratings subtended the same visual angle at EP. The rear projection screen was located at 16.13 meters from EP, effectively at an infinity accommodation distance. The calibration target illuminators were battery operated six volt miniature indicator lamps mounted in housings with a 3.18 cm aperture. The housings were mounted so that the illuminator was not visible to the observer, and so that all targets were of equal luminance to the observer. The infinity target was projected onto the screen at E by the projector at F.

III. Display Simulators

Two display simulators were used. The near beam splitter, A, simulated the helmet mounted display devices. The far beam splitter, B, simulated the "head-up display" devices in which the beam splitter is aircraft mounted. Each of the display simulators consisted of a beam splitter and a projector which could be adjusted to project the virtual image seen by the observer at distances from 1 meter to infinity. The image reflected to the observer by the far beam splitter was generated by the projector at I. The image reflected from the near beam splitter was generated by the projector at K. The image projected by both projectors is shown in Figure 4.

The projector at G provided a small red fixation point on the screen and the projector at F provided, in addition to the accommodation infinity target, various environmental scenes during the procedure.

The bite plate holder was mounted on a metal plate near EP. The holder was equipped with calibrated slides so that the bite plate could be positioned vertically, horizontally and laterally to reproducible locations to accommodate each observer and position the right eye of the observer at EP.

CALIBRATION

The apparent depths at which the virtual images reflected by the beam splitters were projected were measured with a calibrated telescope mounted at EP. Scales were mounted on the focus knobs of the two projectors. The apparent depths of the images were the same as the distances of the calibration targets, 1.25, 2.0, 2.5, 5, 10 meters and collimated, or optical infinity. The amplitude of accommodation required to resolve the targets is shown in Table I. The visual angle subtended by the white line of the accommodation calibration targets was calculated to be 10 minutes, 30 seconds. Because of the cumbersome procedure required to adjust the focus of the near beam splitter, only the 2 meter, 10 meter, and infinity projection distances were used.

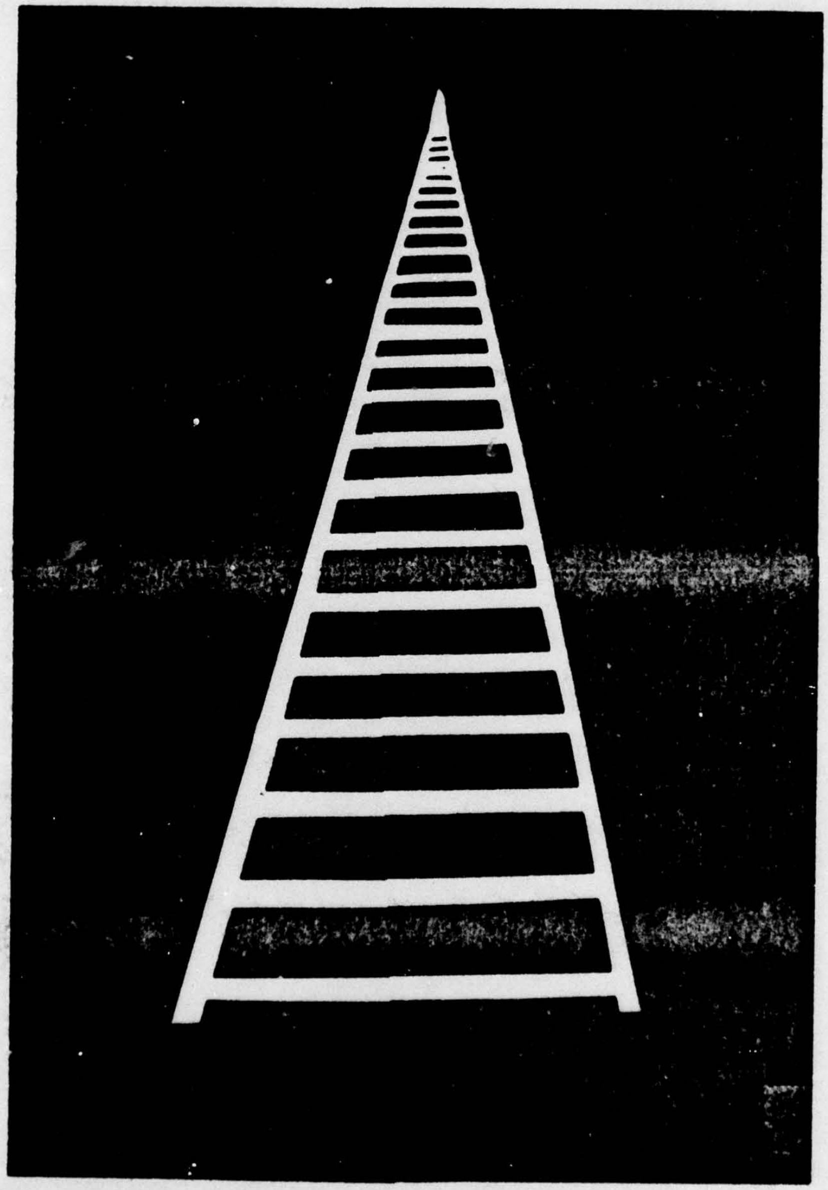


FIGURE 4. Image Reflected from Beam Splitters

TABLE I

TARGET DISTANCE AND ACCOMMODATION REQUIRED FOR RESOLUTION

Target Distance (Meters)	Accommodation Required (Diopters)
1.25	0.80
2.00	0.50
2.50	0.40
5.00	0.20
10.00	0.10
∞	0.00

The luminances of all targets - calibration targets, rear projection screen images and virtual images - were measured with a Pritchard photometer mounted at the eye point. The photometer was calibrated with a Gamma Scientific 100 foot Lambert standard source. The luminances of the varous targets are shown in Table II.

PROCEDURE

The observer was seated in an adjustable seat at the EP end of the experimental room. One experimenter looked through the camera while the other experimenter assisted the observer in adjusting the dental impression bite plate until the right eye was in the required location and in sharp focus for the experimenter at the camera. Identical far beam splitter and screen targets were then turned on. If the two targets were exactly overlapped, the position of the observer was correct. The bite plate holder position values were recorded so that the biteplate could be repositioned for the observer at subsequent sessions. At the start of each session, the positioning of the observer was checked by the camera focus and image overlap procedures. When the proper position was verified, the observer was positioned and each calibration target was lowered into position in the observer's line of sight. The observer fixated on the target and the experimenter photographed the eye and, thus, the Purkinje images of the source at J. Following the six calibration photographs, the appropriate experimental sequence was photographed. In a typical experimental sequence the experimenter placed a card at EP which identified the observer, the date, and the experimental condition and photographed the card. In that way the data for each experimental condition was identified. Next, the observer was positioned on the bite plate and looked at a scene projected onto the screen at E. The far beam splitter (or near beam splitter or no beam splitter as appropriate) was placed in position. Five seconds after the beam splitter was positioned, the experimenter pressed a switch which activated the camera and synchronized flash lamp, J. The experimenter then advanced the projector, F, to remove the scene from the screen, E, and cocked the camera, H. At the end of one minute, the next scene was projected onto the screen and the procedure was repeated. After five photographs were made, the apparatus was adjusted for the next experimental condition and the procedure was repeated. The experimental design is shown in Table III.

DATA REDUCTION

The 35mm film strips were cut and mounted as individual slides. A white matte board which served as a screen was fixed firmly in position. Each slide was projected onto the screen from a distance such that the image was sufficiently large and clearly defined to permit the distance between the first and fourth Purkinje images to be measured. The outline of the outside edge of the iris of each observer was traced on a paper and used to verify that each projected image of the eye was the same size. If the iris image was larger or smaller than the outline, the projector was adjusted so that the image matched the standard. The distance between the images was measured with vernier scaled calipers. Five measurements were made of each slide and the median of the five readings was used for a datum point. All readings were made by the same person to reduce the variability in the criterion used in making the measurements.

TABLE II

TARGET LUMINANCES

TARGET	AVERAGE LUMINANCE
Accommodation Calibration (white stripe)	0.09 ft. L.
Beam Splitter	
1. Target	0.04 ft. L.
2. Background	0.0004 ft. L.
Environmental Scene	
1. Building in forest - aerial view	0.0076 ft. L.
2. Helicopter, sky and sea	0.0171 ft. L.
3. Submarine at sea	0.0115 ft. L.
4. Aircraft against sky	0.0109 ft. L.
5. Object in sea	0.0123 ft. L.
Fixation Point	0.002 ft. L.

TABLE III

EXPERIMENTAL DESIGN

Image Distance (Meters)	Beam Splitter: Near	Beam Splitter: Far	No Beam Splitter: Control	No Beam Splitter: Calibration
1.25		E		M
2.00	A	F		N
2.50		G		O
5.00		H		P
10.00	B	I		Q
∞	C	J		R
No Image	D	K	L	

RESULTS

An analysis of variance was performed on the calibration data for each observer. The data were treated individually since the first and fourth image distances and variations with accommodation are individually characteristic. The results of those analyses are shown in Tables IV and V. The F-ratio for the differences between calibration conditions were significant at the 0.001 level for both observers. The distances between the first and fourth Purkinje images for the calibration trials was plotted as a function of diopters of accommodation required to focus the calibration targets. These plots are shown in Figures 5 and 6. The accommodation in diopters for each experimental condition was then read from the calibration plots.

Analyses of the variance were also performed on the experimental data of each observer and are shown in Table VI and VII. For observer PEM, only the F ratio for the interaction of experimental conditions with scenes viewed was significant. Since neither of the main effects F-ratio, (experimental condition or scenes viewed) was significant, the significant interaction is not considered to be particularly meaningful. For observer TN, the F-ratios for both the experimental condition and the interaction of the scenes viewed and the experimental condition were significant. In order to further examine the influence of the experimental condition, the significance of the differences between pairs of experimental condition means were evaluated. The results of those evaluations are shown in Table VIII. The t values shown in the table indicate that the near beam-splitter condition differed significantly from all of the far beam-splitter and no beam splitter conditions. The strongest accommodation recorded was for the condition in which the far beam splitter was in position but no reflected image was presented to the observer, condition K. The least accommodation recorded was for the comparable near beam splitter condition, condition D. Both of the near beam splitter conditions which were conducted for observer TN showed insignificant levels of accommodation.

The average accommodation recorded for observer PEM was infinity or zero diopters, in every condition.

DISCUSSION

The results obtained in the present study suggest that the extent of collimation of the target presented via an aircraft mounted virtual image display system may influence the focus of at least some users of such displays.

There are several questions raised by the data reported above. The interval between the presentation of the experimental conditions and the recording of the level of accommodation was constant for both observers over all conditions. The finding that one observer showed accommodation levels that differed from infinity in some of the conditions while the other did not, raises questions with respect to the dynamic character of the accommodation response. It is possible that the selected interval between the presentation of the target and the photograph of the Purkinje images was not appropriate for all observers. The period of the accommodation response may be as individually characteristic as the Purkinje image difference which was chosen as the measure of the response.

TABLE IV

ANALYSIS OF VARIANCE SUMMARY TABLE - CALIBRATION

Observer PEM

Source of Variance	df	F
Distance	5	117.203*
Repetitions	8	2.78
Error	40	
TOTAL	53	

*P<0.001

TABLE V

ANALYSIS OF VARIANCE SUMMARY TABLE - CALIBRATION

Observer TN

Source of Variance	df	F
Distance	5	44.73*
Repetitions	6	4.97**
Error	30	
TOTAL	41	

*P < 0.001

**P < 0.05

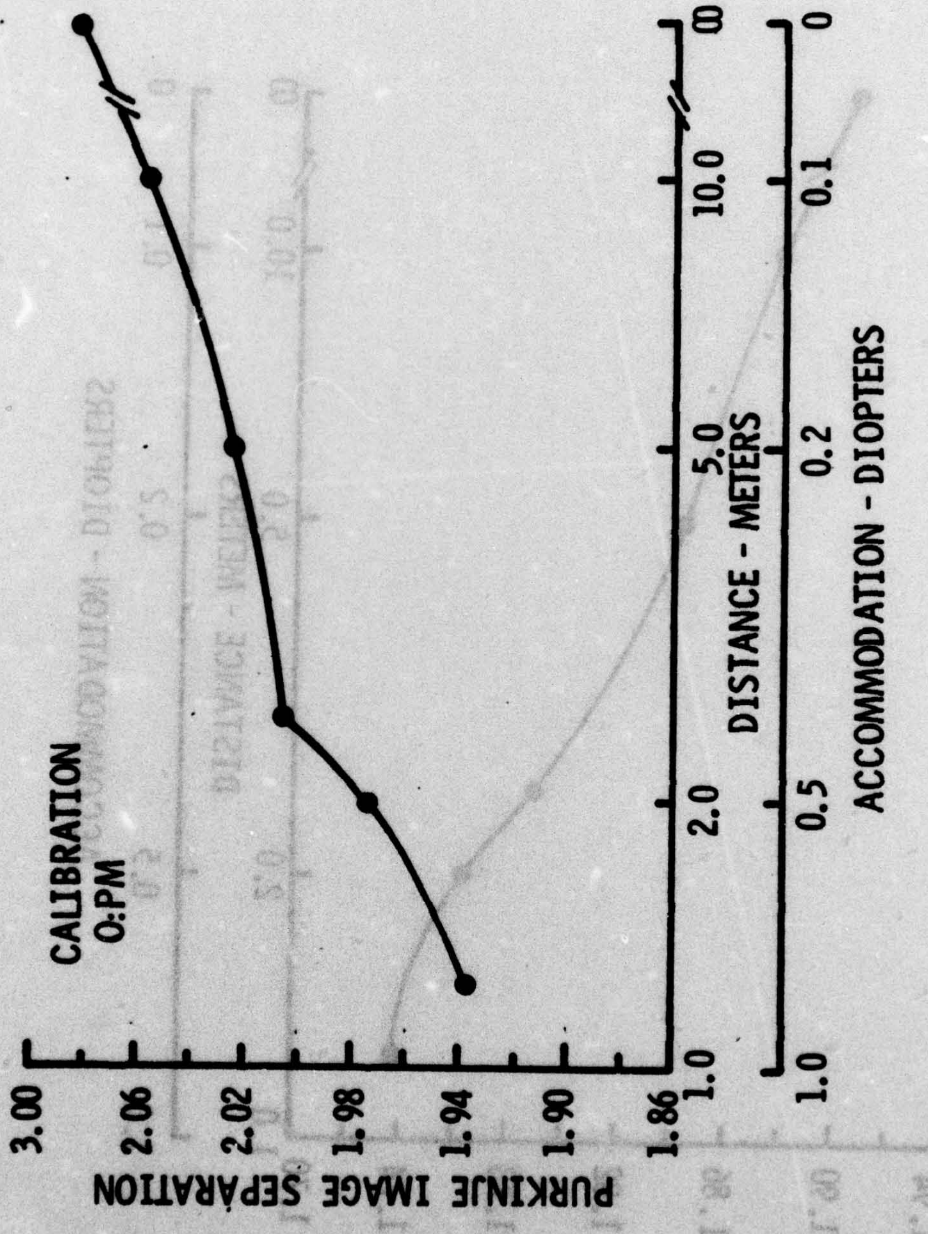


FIGURE 5. Purkinje Image Separation as a Function of Calibration Target Distance and Diopters of Accommodation Required - Observer PEM.

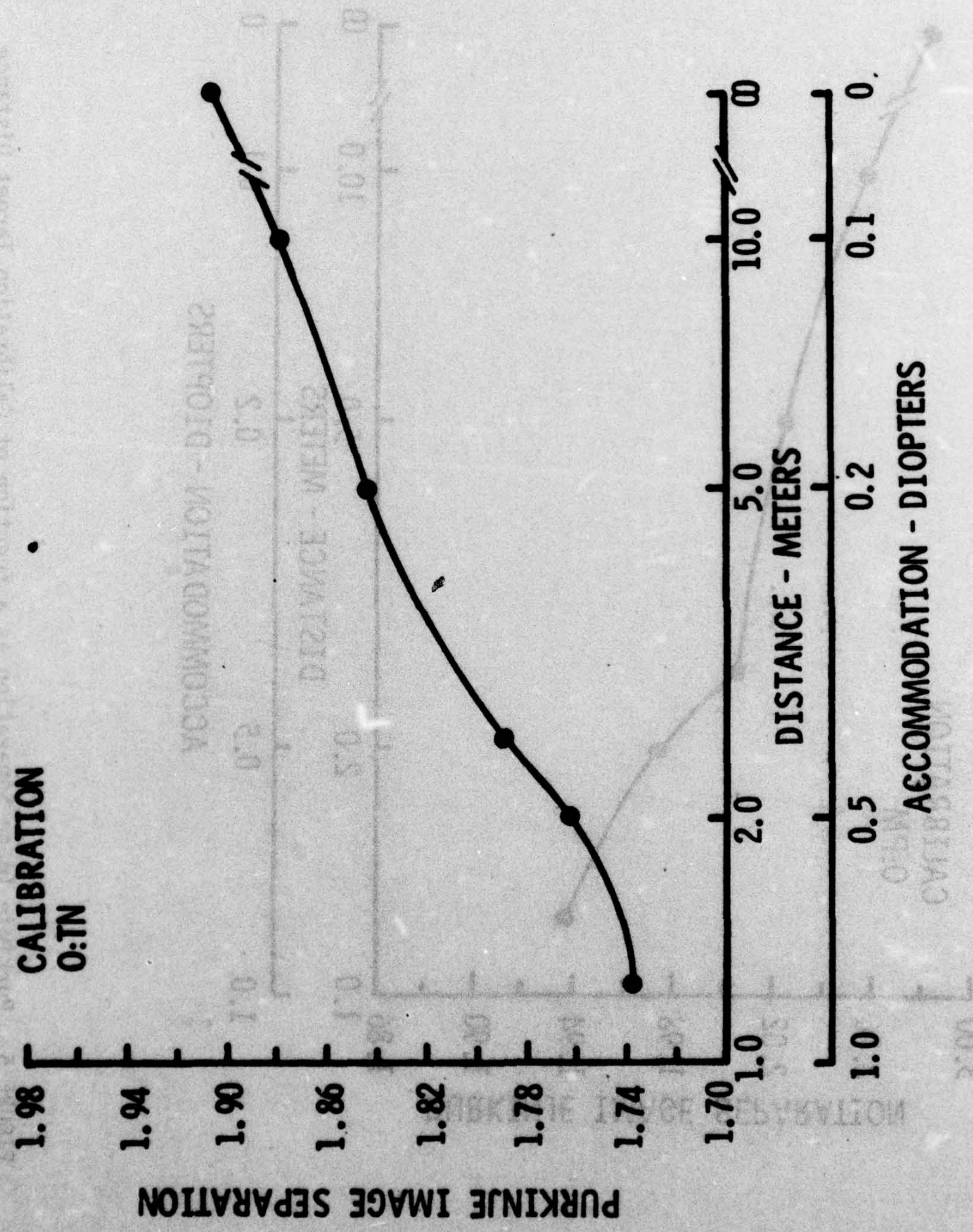


FIGURE 6. Purkinje Image Separation as a Function of Calibration Target Distance and Diopters of Accommodation Required - Observer TN.

TABLE VI

ANALYSIS OF VARIANCE SUMMARY TABLE - EXPERIMENTAL

Observer PEM

Source of Variance	df	F
Beam Splitter Condition (C)	11	1.54
Scene (S)	5	3.96
C X S	55	2.22*
Error	288	
TOTAL	359	

*P < .01

TABLE VII

ANALYSIS OF VARIANCE SUMMARY TABLE - EXPERIMENTAL

Observer TN

Source of Variance	df	F
Experimental Condition (C)	9	7.48*
Scene (S)	5	2.08
C X S	45	1.75**
Error	240	
TOTAL	299	

*P < 0.001
**P < 0.05

TABLE VIII

SIGNIFICANCE OF THE DIFFERENCE BETWEEN PAIRS OF MEANS

Observer TN

ts

Experimental Condition (Measured Accommodation-Diopters)	Experimental Condition C	D	E	F	G	H	I	J	K	L
C (0.01)										
D (0.006)	0.56									
E (0.07)	*3.47	*4.03								
F (0.08)	*4.05	*4.61	0.58							
G (0.07)	*3.69	*4.25	0.22	0.36						
H (0.05)	**2.32	*2.88	1.15	1.73	1.37					
I (0.08)	*4.33	*4.89	0.86	0.28	0.64	**2.01				
J (0.07)	*3.82	*4.39	0.35	0.23	0.14	1.51	0.5			
K (0.10)	*5.66	*6.13	**2.19	1.61	**1.97	*3.34	1.33	1.83		
L (0.07)	*3.69	*4.25	0.21	0.35	0.002	1.37	0.64	0.14	**1.97	

*P < 0.01

**P < 0.05

Another question raised by the data is the meaning of the magnitude of the accommodation response in the far beam splitter condition with no image projected, condition K. The 0.1 diopter accommodation for observer TN was of greater magnitude than that of any of the other conditions. One possible conclusion is that the near beam splitter did not have as great an effect as a stimulus for accommodation because the beam splitter is so close to the eyes that reflex responses to the beam splitter itself is not a very probable occurrance. The far beam splitter, located at 57 centimeters from the observer provides a much stronger stimulus for reflex accommodation, therefore, produces a greater accommodation response than the near beam splitter. Still another question which could not be quantified in the present procedure is the extent to which the environmental stimuli, represented by the scenes projected on the screen at E, remain in clear focus during the procedure. Subjective reports by the observers indicated that the scenes were clearly visualized. An attempt should be made to quantify the extent to which that did occur.

While the results of the present study provide some insights into the visual effects of virtual image-type displays, there are still important questions which remain unanswered. Continuous monitoring of the accommodation state of the eye, and a measure of the resolution of the environmental targets will help to elucidate some of the areas of concern. Plans are underway to explore further the problems which remain unanswered.

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2. NAS NRC Committee on Vision Report on Working Group on Head-Up and Helmet Mounted Displays, November 1973.

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